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Multi-objective Optimum Structural Design of Marine Structure Considering the Productivity

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KEY WORDS: Distance method, Genetic algorithms, Multi-objective function optimization, Panel block, Pareto optimal set

ABSTRACT: *It is necessary to develop an efficient optimization technique to optimize engineering structures that have given design spaces, discrete design values, and several design goals. In this study, an optimum algorithm based on the genetic algorithm was applied to the multi-object problem to obtain an optimum solution that simultaneously minimizes the structural weight and construction cost of panel blocks in ship structures. The cost model was used in this study, which includes the cost of adjusting the weld-induced deformation and applying the deformation control methods, in addition to the cost of the material and the welding cost usually included in the normal cost model. By using the proposed cost model, more realistic optimum design results can be expected.*

1. Introduction

In the context of ship structural design, many studies on the optimum design of ships structure have been carried out for the last several decades. However, most of them were concerned with the minimization of a single object function with structural weight or construction cost. To achieve more economic design, it is necessary to employ the concept of multi-object optimization which can give more reasonable structural design result satisfying both the minimum structural weight and the minimum construction cost at the same time. And since the adjusting work takes a considerable portion in block assembly, it is also necessary to take into account the cost for adjusting work for more reasonable cost model in optimization procedure.

This paper is concerned with the optimum design of panel blocks found in a ship structure. In this study, multi-objective optimization procedure has been developed based on the genetic algorithm to obtain the design result which satisfies both minimum weight and minimum cost. Distance method which is one of multi-objective optimization method based on the genetic algorithm is used to obtain the Pareto optimal set. In the cost model of the present study, the cost for adjusting work itself and the cost when deformation control method is applied are taken into account in addition to the cost of material and the construction cost which is usually calculated based on the welding work.

2. Optimization Method

The genetic algorithm is the optimization algorithm developed based on the principles of survival of fittest and natural selection in the theory of evolution which were proposed by Darwin (Michalewicz, 1999). That is, in the genetic algorithm, the evolution rule in nature is applied to the optimum problem. In this method compatibility is imposed to several design points based on the value of the objective function and violation rate of constraints. Details of the genetic algorithm can be seen in the text book about optimum theory (Gen and Cheng, 2000).

In this study GENOCOP III (GEnetic algorithm for Numerical Optimization for COnstrained Problems III) is used, which was proposed by Michalewicz (1999) and the improved method based on GENOCOP I which was adequate in linear constraint optimization problem. GENOCOP I can always generate individuals which can satisfy constraint conditions by redefining intervals of variables from the processes of cross and mutation. In GENOCOP III, the linear constraints are treated as in GENOCOP I and the repair strategy is used to treat the nonlinear constraints. The repair strategy of GENOCOP III is to generate the initial population, called the search population, satisfying the linear constraints and to generate another population, called the reference population satisfying the nonlinear constraints, and then violation which can occurs during crossover and mutation processes is repaired by linking the search and reference points. Figure 1 illustrates the repair process, in which r1, r2, r3 and r4 are examples of reference points, and s1, s2, s3 and s4 are those of search points.

Distance method is used to obtain the Pareto optimal set. Figure 2 illustrates the concept of the distance method with

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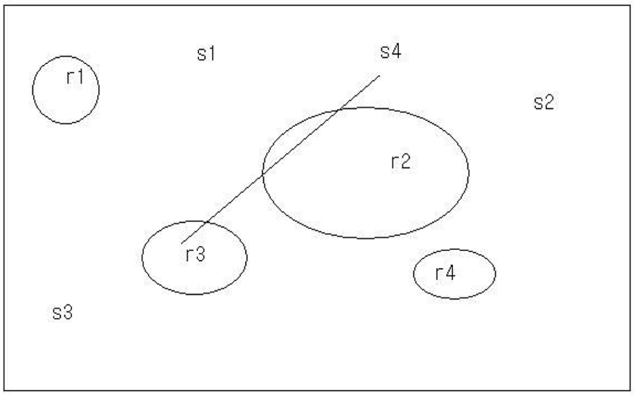

Fig. 1 Repair process

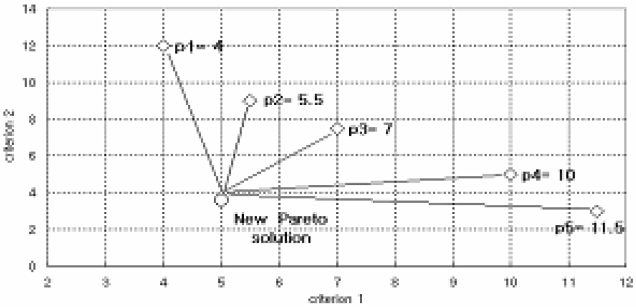

Fig. 2 Potential values and concept of distance method

the potential values. In the distance method, the shortest distance between the all Pareto solutions and the newly generated solution is used to compute the compatibility (Gen and Cheng, 2000).

The overall flow of the distance method is as follows.

1) Initialization of design variables and potential value
2) Compute new population and check the stopping criteria
3) Compute the distance of the newly generated solution
4) Compute the compatibility
5) Reset the potential value
6) Stop iteration if the stopping criteria are satisfied

3. Cost Model

In the multi-objective optimization problems, the minimizing the structural weight and the cost has been simultaneously solved and cost model consisting of material cost and welding cost as the construction cost has been usually used (Na, 2005).

In order to estimate a more realistic construction cost, the cost of adjusting the deformation and the cost required in applying the deformation control method are included in the present cost model. Therefore, the present cost model consists of following four items.

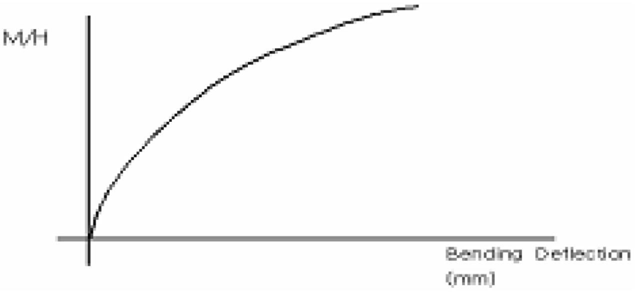

Fig. 3 Relation between man-hour and transverse distortion (bending deflection)

Table 1 Effect of deformation control methods

No	Method	DR	Weight & cost
1	No application	0%	-
2	Constraint method	30%	Cost for installing constraint jigs
3	Attaching carling	50%	Weight of carling & cost for welding carling
4	Inverse deformation	40%	Working cost
5	MTM	60%	Cost for installing mechanical tensioning apparatus

(Note) MTM : Mechanical tensioning method
DR : Deformation reduction rate

- Material cost
- Welding cost
- Cost to applying the deformation control method
- Cost for adjusting work

Since the real weld-induced deformation occurs in the combined form of several deformation types, accounting for all deformation types must be difficult. Therefore, as for illustration of using the cost model which involves the cost of applying the deformation control methods, only the transverse distortion is considered in this study, which is the most deformation type in the weld-induced deformation.

The adjusting cost is estimated in terms of man-hour per unit deformation (bending deflection) and is assumed to be non-linear relation as in Fig. 3. Table 1 illustrates the quantitative effect of applying the several deformation control methods, which were deduced from several references (Lee, 2004; Lee and Kim, 2006).

4 Applications to Real Panel Block Model

4.1 Panel block model

The double hull structure of oil tanker in Fig. 4 is selected as the panel block model to illustrate the application of the

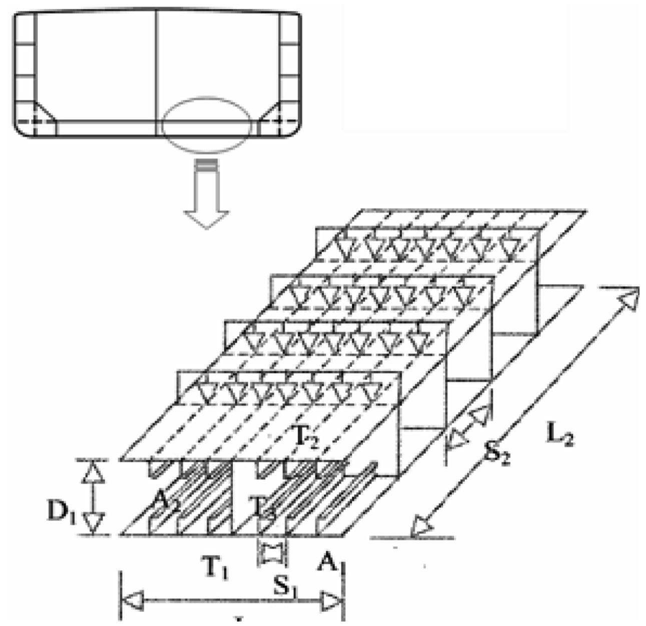

Fig. 4 Panel block model of double hull oil tanker

present optimization method. The principal dimensions are as follows.

LBP : L = 320 m
Breadth : B = 60 m
Depth : D = 30 m
Draft : T = 22 m
Transverse length of block : $L1$ = 20 m
Longitudinal length of block : $L2$ = 50 m
Distance between inner & outer panels

$$: D_1 = 28B + 205\sqrt{T} \tag{1}$$

4.2 Design variables

Design variables for the present model are as follows.

$x1 = T_1$: Thickness of outer panel
$x2 = T_2$: Thickness of inner pan디
$x3 = T_3$: Thickness of center girder
$x4 = T_4$: Thickness of transverse floor
$x5$ = Material property number defined as in Table 2
$x6$ = Deformation control number : 1~5 (see Table 1)
$x7 = S_1$: Longitudinal space
$x8 = S_2$: Transverse space

All design variables are discrete. Thickness is increased or decreased by 0.5 mm, and longitudinal and transverse space by 10 mm. Ranges of design variables are as follows.

$5 \leq xi \leq 50$ for i = 1, 2, 3 and 4
$x5$ = Integer between 1 and 3
$x6$ = Integer between 1 and 5
$700 \leq x7 \leq 1500$
$4000 \leq x8 \leq 6000$

Table 2 Material properties

$x5$	K	Mc (US$/ton)	σ_y (MPa)
1	1.00	450	235
2	0.78	480	315
3	0.72	530	390

(Note) K : Higher tensile stress factor
Mc : Unitary material cost
σ_y : Yield stress

4.3 Object functions

There are two object functions for the present optimization problem, that is, structure weight (F_1) and construction cost (F_2), and their definitions are as follow.

(1) Structure weight, F_1

Structure weight is the sum of weights of panels, longitudinals and transverse floors.

$$F_1 = W_1 + W_2 + W_3 \tag{2}$$

where

- W_1 : Weight of panels

$$W_1 = (T_1 + T_2)L_1L_2 + T_3D_1L_2 \times 7.85 \tag{3}$$

- W_2 : Weight of longitudinals

$$W_2 = 4AL_2\{\mathrm{int}(\frac{L_1/2}{S_1}) - 1\} \times 7.85 \tag{4}$$

A : Cross-sectional area

- W_3 : Weight of transverse floors

$$W_3 = D_1T_4L_1\{\mathrm{int}(\frac{L_2}{S_2}) - 1\} \times 7.85 \tag{5}$$

(2) Construction cost, F_2

Cost is defined as the sum of following seven items.

$$F_2 = C_M + C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \tag{6}$$

where

- C_M : Material cost

$$C_M = F_1 \times M_C \tag{7}$$

F_1 is given as Eq. (2) and M_C is unitary material cost given in Table 2.

- C_1 : Welding cost of longitudinals

$$C_1 = 4L_2\{\mathrm{int}(\frac{L_1/2}{S_1}) - 1\} \times C_u \tag{8}$$

- C_2 : Welding cost of center girder

$$C_2 = [(D_1\{\mathrm{int}(\frac{L_2}{S_2}) - 1\}) + (S_2\{\mathrm{int}(\frac{L_2}{S_2})\} \times 2] \times C_u \qquad (9)$$

- C_3 : Welding cost of transverse floors

$$C_3 = 2\{\mathrm{int}(\frac{L_2}{S_2}) - 1\} \times L_2 \times C_u \qquad (10)$$

- C_4 : Welding cost of slots

$$C4 = [2\{\mathrm{int}(\frac{L_1/2}{S_1}) - 1\}] \times [\{\mathrm{int}(\frac{L_2}{S_2}) - 1\}] \times Cu \qquad (11)$$

- C_5 : Cost of applying the deformation control method
- C_6 : Cost of adjusting work

4.4 Constraints

As constraints in design, this study follows the constraints specified in Part 4 Ch.9 of Lloyd classification society rule (Lloyd's Register, 2007).

$$\begin{aligned} T_1 &= \frac{S_1}{J}+2 \le x_1 \qquad (12) \\ T_2 &= \frac{t_0}{\sqrt{2-F_B}} \le x_2 \\ T_3 &= (0.008D_1+1.0)\sqrt{k} \le x_3 \\ T_4 &= (0.007D_1+1.0)\sqrt{k} \le x_4 \\ Z &= 0.0056kh_1S_1l_eF_1F_s \le Z_l \end{aligned}$$

where

$$J = 1720.5\sqrt{\frac{1-1/\alpha}{\sigma_0}} \qquad \text{for } \alpha \le 2$$

$$= 860.7\sqrt{\alpha/\alpha_0} \qquad \text{for } \alpha \ge 2$$

$\alpha = \sigma_0/\sigma_c$

σ_0 = Specified minimum yield stress in MPa

σ_c = Maximum compressive hull vertical bending stress in MPa

$t_0 = 0.005\,s\sqrt{kh_1}$

l_e = Effective length of member

Table 3 Optimum design results

O.P.	T_1 (mm)	T_2 (mm)	T_3 (mm)	T_4 (mm)	M	W	S_1 (mm)	S_2 (mm)
A	33.5	25.5	28.0	6.5	1	5	770.0	6920.0
B	28.5	28.5	32.5	5.0	1	5	720.0	5660.0
C	27.0	26.5	33.0	7.5	1	3	700.0	5640.0
D	32.0	22.5	27.0	5.0	3	5	860.0	6880.0
E	30.0	19.0	21.0	7.5	3	5	720.0	4300.0
F	26.0	18.0	32.0	16.0	2	1	710.0	5990.0

(Note) O.P. : Optimum point
M : Material property number
W : Deformation control method number(see Table 1)

Table 4 Pareto solutions

O.P.	Weight (ton)	Cost (US$)	Remark
A	559.6	600359.8	Min. cost
B	551.5	603972.1	
C	536.5	610681.3	
D	514.8	623395.2	
E	493.4	631454.5	
F	485.6	657287.5	Min. weight

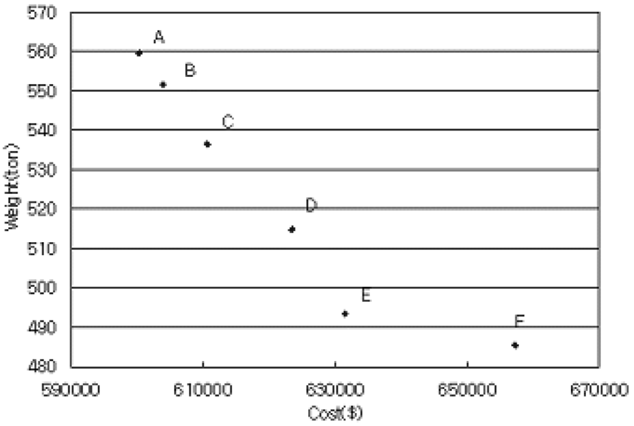

Fig. 5 Pareto solutions for the present panel block model

4.5 Optimum design results

For the present panel block models, six Pareto optimal solutions have been obtained as they are designated from A to F in Table 3. In the same table, detail dimensions are shown. The weights and costs for Pareto optimal points are listed in Table 4. The points A and F are corresponding to the minimum cost and the minimum weight, respectively. The optimal points are plotted as in Fig. 5. As far as the present results are concerned, minimum weight design can be obtained by increasing the portion of high tensile steel. Meanwhile, there is difference depending upon the deformation control method. This means that considering the cost of adjusting work and of applying the deformation control method is important for a more realistic optimum design results. Since the absolute values in the present cost model of adjusting work and applying the deformation control method may be discrepant from the real situation, more reliable values for these costs should be used for the practical application of the present optimization concept.

More optimum points can be generated by applying the presently developed computer codes. In the general sense, designer can choose one of optimum points depending on the design environments. The present multi-objective optimization scheme can produce optimum design results which reflects the variation in construction including not only material and labor costs as well as and any other cost related with it. And these results are supposed to be useful at the decision making stage in choosing more reasonable design result.

5. Conclusions

This study has been concerned with the multi-objective optimum design problem by applying the optimization method based on the genetic algorithm, which can be applied to the optimization problems having discrete design variables. The optimization problem is to simultaneously minimize the structure weight and construction cost. For a more realistic optimum design result, used is the cost model in which costs of adjusting weld-induced deformation and applying the deformation control method are included. The present optimum design concept has been applied to the panel block model found in oil tanker. As far as the optimum design results in this study are concerned, considering the costs of adjusting work and applying the deformation control method is desirable for a more realistic optimum design results. Since the absolute values in the present cost model of adjusting work and applying the deformation control method may be discrepant from the real situation, more reliable values for these costs should be used in the future study.

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